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(64) Method and apparatus for monitoring combustion systems.

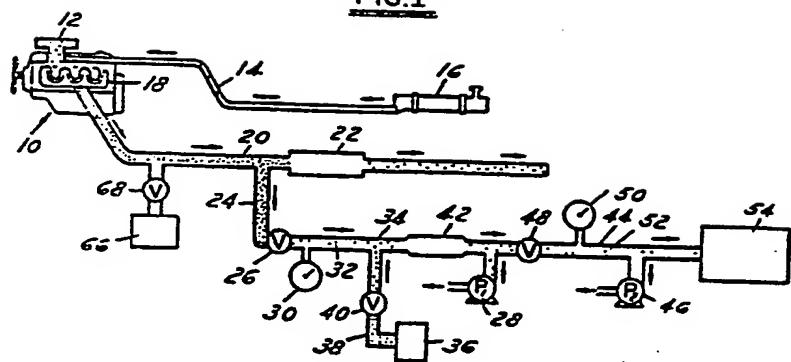
(67) An instantaneous indication of the air to fuel ratio of an air/fuel mixture being fed to a combustion process such as may take place in an internal combustion engine (10) or in a power plant, comprises adding oxygen (from an oxygen source (36) to a sample (32) of the products of the combustion process under conditions sufficient to effect combustion of any unburnt combustible material in the said products (eg in a catalyst chamber (42); analysing the combustion products so obtained, e.g. in a mass spectrometer (54); generating a signal representing the ratio of the oxygen and nitrogen contents of the analysed gases; and controlling, e.g. by means of a microprocessor-controlled valve (40) operable in response to the signal, the amount of oxygen added to the sample so as to maintain therein a predetermined excess of oxygen above that required for stoichiometric combustion. From this signal

and the amount of oxygen is derived fuel to air ratio of the mixture undergoing combustion. Modifications of the method are taught to obtain such information as the hydrogen to carbon ratio of the fuel being burned in the combustion process, the oxygen equivalence of the air/fuel mixture being burned, the air mass flow through the combustion process, the fuel mass flow through the combustion process, instantaneous fuel economy of a vehicle in which a combustion process is being carried out to propel the vehicle, and the oxygen concentration in the exhaust gas from the combustion process.

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FIG.1





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EUROPEAN SEARCH REPORT

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. ²)
X	FR-A-2 451 581 (RICARDO CONSULTING ENGINEERS) * page 8, line 30 - page 11, line 20; page 14, lines 10-23; claim 1; figures 1,2 *	1	G 01 N 31/12 G 01 N 33/00
A,D	US-A-4 146 000 (HATTORI et al.)		
A	US-A-3 927 979 (F. BYRNE)		

TECHNICAL FIELDS
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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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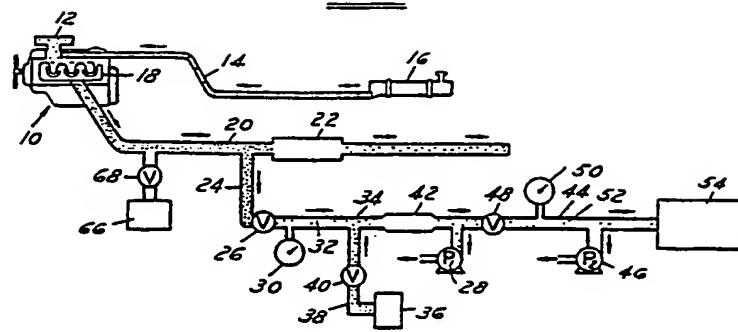
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(54) Method and apparatus for monitoring combustion systems.

A2
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An instantaneous indication of the air to fuel ratio of an air/fuel mixture being fed to a combustion process such as may take place in an internal combustion engine (10) or in a power plant, comprises adding oxygen (from an oxygen source (36)) to a sample (32) of the products of the combustion process under conditions sufficient to effect combustion of any unburnt combustible material in the said products (eg in a catalyst chamber 42); analysing the combustion products so obtained, e.g. in a mass spectrometer (54); generating a signal representing the ratio of the oxygen and nitrogen contents of the analysed gases; and controlling, e.g. by means of a microprocessor-controlled valve (40) operable in response to the signal, the amount of

oxygen added to the sample so as to maintain therein a predetermined excess of oxygen above that required for stoichiometric combustion. From this signal and the amount of oxygen is derived fuel to air ratio of the mixture undergoing combustion. Modifications of the method are taught to obtain such information as the hydrogen to carbon ratio of the fuel being burned in the combustion process, the oxygen equivalence of the air/fuel mixture being burned, the air mass flow through the combustion process, the fuel mass flow through the combustion process, instantaneous fuel economy of a vehicle in which a combustion process is being carried out to propel the vehicle, and the oxygen concentration in the exhaust gases from the combustion process.

FIG.1



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DESCRIPTION.**" METHOD AND APPARATUS FOR MONITORING A COMBUSTION SYSTEM."**

This invention relates to methods and apparatus for monitoring combustion systems.

A number of combustion monitoring systems have been proposed. For example US-A-3,926,154 discloses a fuel control system which 5 employs an oxygen sensor and a sensor for unburned hydrocarbon in the tailpipe of an automotive vehicle in which fuel is burned in an internal combustion engine. In addition, a throttle angle transducer is provided for supplying an input to a control device.

US-A-4,052,968 discloses a control system for adjusting the 10 air-to-fuel ratio of an internal combustion engine which employs an air to fuel ratio detector and a temperature sensor. An intake air pressure detecting device is mounted in the intake manifold of the engine, and when the detected pressure in the intake manifold becomes greater than a predetermined threshold, additional fuel is supplied 15 by means of an auxiliary fuel jet provided in the carburetor.

US-A-4,146,000 discloses an air flow control system which employs an acceleration/deceleration sensor connected to the intake manifold for supplying a signal to a control unit. The purpose of 20 this sensor is to detect a steady state operation of an internal combustion engine in order to gradually decrease the amount of opening and closing of an air bypass valve in a carburetor for the internal combustion engine.

None of the control systems disclosed in these publications are capable of continuously monitoring the combustion process in a manner 25 which allows the generation of instantaneous indications of the operating characteristics of the combustion process, such as the air to fuel ratio of the mixture being fed to the combustion process,



the hydrogen to carbon ratio of the mixture; the oxygen equivalence of the mixture, the air mass flow of the mixture; the fuel economy of the vehicle to which the engine is fitted; or the oxygen content of the products of combustion.

5 According to the present invention, there is provided a method of continuously monitoring a combustion process comprising the steps of adding oxygen to a sample of the products of the combustion process under conditions sufficient to effect combustion of unburnt combustible material in the products of the combustion process; analysing the combustion products so obtained; generating a signal representative of the ratio of the oxygen and nitrogen contents of the combustion products so analysed; controlling in response to the signal the amount of oxygen added to the sample of the products of the combustion process so as to maintain a predetermined excess of oxygen in the analysed combustion products above that required for stoichiometric combustion of unburnt combustible material in the products of the combustion process.

The invention also includes apparatus for continuously monitoring a combustion process comprising means for withdrawing a sample of the products of the combustion process; means for adding oxygen thereto and for effecting combustion of unburnt combustible material in the products of the combustion process; means for analysing the combustion products so obtained; means for generating a signal representative of the ratio of the oxygen and nitrogen contents of the combustion products so analysed; and means operable in response to the signal for controlling means for adding oxygen.



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The invention is primarily suitable for obtaining on a continuous basis an instantaneous indication of the air to fuel ratio of an air/fuel mixture being fed to a combustion process. Such information may be used in a motor vehicle for precisely controlling the air/fuel ratio of the mixture being fed to the internal combustion engine as to control the combustion products which are achieved during the combustion process. This same type of data may be used in power house applications in order to achieve a precisely correlated fuel to air mixture which ensures the most economical operation of the power generation system.

The method of the invention may also be used to obtain on a continuous basis an instantaneous indication of both the air to fuel ratio and the hydrogen to carbon ratio of an air/fuel mixture being fed to a combustion process. Additionally, an instantaneous indication of both the air to fuel ratio and the oxygen equivalence of an air/fuel mixture being fed to a combustion process may be obtained.

An instantaneous indication of both the air to fuel ratio and the air mass flow of an air/fuel mixture being fed to a combustion process may also be obtained. In a similar manner, the same data may also be obtained along with the fuel mass flow of that same air/fuel mixture being fed to a combustion process.

By use of a modification of the basic method of this invention it is possible to obtain on a continuous basis for a moving, internal combustion driven vehicle instantaneous indications of the air to fuel ratio, the air mass flow, fuel mass flow and instantaneous fuel economy of an air/fuel mixture being fed to the combustion process. This same basic method may also be used both on an engine driven vehicle and a stationary combustion process for obtaining on a continuous basis an instantaneous indication of both the air to fuel ratio and the oxygen concentration in the exhaust gases of an air/fuel mixture being fed to a combustion process.



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The obtaining of the data as described above is of value because each type of data can be used in controlling the combustion process to achieve the maximum efficiency for that process. Such controls can also be used to obtain maximum fuel economy from operation 5 of the combustion process. Still another way of using the methods of monitoring a combustion system as disclosed and claimed herein is to aid in reducing the least desirable components which are contained in the exhaust gas stream from the process.

In accordance with a preferred embodiment of the invention, 10 an instantaneous indication of the air to fuel ratio of an air/fuel mixture being fed to a combustion process is obtained by following general steps. An air/fuel mixture is continuously passed through a combustion process to generate a first stream of gaseous material. This first stream of gaseous material may contain (a) unburned fuel, 15 (b) partially oxidized fuel, (c) carbon monoxide, (d) carbon dioxide, (e) water vapor, (f) nitrogen, (g) oxygen, (h) inert gases normally found in air, or (i) a mixture of any or all of (a) through (h). A sample portion of the first stream of gaseous material is continuously withdrawn into a volume at a first pressure below atmospheric pressure. 20 The first pressure below atmospheric pressure is a pressure that, at the temperature of the sample portion continuously withdrawn, the water vapor contained therein will not condense. The sample portion continuously withdrawn forms a second stream of gaseous material that has the same compositional makeup on a volume percentage basis as the first 25 stream of gaseous material but at a reduced pressure.



A controlled source of oxygen addition is continuously provided to the second stream of gaseous material. The controlled source of oxygen addition is continuously controlled by application of a control signal thereto. The 5 control signal is applied in a manner that the oxygen is added to the second stream of gaseous material at a rate proportional to the strength of the control signal applied to the controlled source of oxygen addition. The control signal is continuously developed to a strength which results 10 in the controlled source of oxygen addition adding to the second stream of gaseous material sufficient oxygen that there is after oxygen addition a predetermined amount of oxygen in excess of that required to stoichiometrically oxidize any (a) unburned fuel, (b) partially oxidized fuel, 15 and (c) carbon monoxide to (d) carbon dioxide and (e) water vapor.

A sample portion of the second stream of gaseous material is continuously withdrawn into a volume at a second pressure substantially below the first pressure. The sample is withdrawn after the oxygen has reacted with 20 (a) unburned fuel, (b) partially oxidized fuel, and (c) carbon monoxide. This second pressure is a pressure that, at the temperature of the sample portion continuously withdrawn from the second stream of gaseous material, the 25 water vapor contained therein will not condense. The sample portion continuously withdrawn forms a third stream of gaseous material that has the same composition makeup based on fully oxidized carbon and hydrogen on a molar basis as the second stream of gaseous material plus added 30 oxygen but at a reduced pressure.

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The third stream of gaseous material is continuously subjected to analysis by a mass spectrometer to generate on a continuous basis an output signal. The output signal developed is indicative of the ratio of oxygen to nitrogen in the third stream of gaseous material.

5 The control signal for application to the controlled source of oxygen is continuously generated from the output signal generated by the mass spectrometer. The control signal strength is generated in a manner that (1) when the oxygen

10 signal of the third stream of gaseous material being measured by the mass spectrometer is at a predetermined level, the control signal strength has a predetermined strength which ensures the predetermined amount of oxygen in excess of that required to stoichiometrically oxidize

15 the components is added to the second stream of gaseous material; and (2) when the oxygen signal of the third stream of gaseous material being measured by the mass spectrometer falls away from the predetermined level, the control signal has a strength that ensures an amount of

20 oxygen greater than the predetermined amount of oxygen is added to the second stream of gaseous material. In this manner, the measured amount of oxygen is returned to the predetermined level of oxygen, the instantaneous amount of oxygen being added to the second stream of gaseous material

25 and the oxygen to nitrogen ratio being related to the fuel to air ratio of the air/fuel mixture being burned in the combustion process.

Above there has been described a basic method disclosed in this specification for obtaining on a continuous basis an instantaneous indication of the air to fuel ratio of an air/fuel mixture being fed to a combustion process. Hereafter will be pointed out several ways of modifying the basic method of our invention so that additional data may be obtained from the combustion process.

If one desires to obtain on a continuous basis both an instantaneous indication of the air to fuel ratio and the hydrogen to carbon ratio of an air/fuel mixture being fed to a combustion process, the following method is 5 used. The method is the same as the method previously described to obtain the air to fuel ratio, but the mass spectrometer generates not only the first output signal indicative of the ratio of oxygen to nitrogen in the third gas stream but also another output signal indicative of the 10 ratio of oxygen to carbon dioxide in the third stream of gaseous material. The first output signal is used as described above to obtain the air to fuel ratio information. The other output signal is used to continuously generate a signal whose strength is proportional to the 15 ratio of hydrogen to carbon in the fuel in the air/fuel mixture being burned in the combustion process. Knowing the air/fuel ratio and the oxygen to carbon dioxide ratio one may calculate the hydrogen to carbon ratio using known equations.

20 If one desires to obtain on a continuous basis an instantaneous indication of both the air to fuel ratio and the oxygen equivalence of the air/fuel mixture being fed to the combustion process, it is only necessary to continuously subject the third stream of gaseous material to 25 analysis by a mass spectrometer to generate on a continuous basis an output signal indicative of the ratio of oxygen to nitrogen. This output signal generated by the mass spectrometer may be used as the control signal for application to the controlled source of oxygen. The output 30 signal can also be used to generate continuously a signal whose strength is related to the oxygen equivalence for the air/fuel mixture being burned in the combustion process. This is so because oxygen equivalence is mathematically related to the oxygen to nitrogen ratio.

The basic method of this invention may be modified, as will be described below, so as to be usable for obtaining on a continuous basis an instantaneous indication of both the air to fuel ratio and the air mass flow of an air/fuel mixture being fed to a combustion process. In this situation, the basic method is modified by continuously injecting/argon into the first stream of gaseous materials at a known, fixed mass injection rate. The first stream of gaseous materials is the stream generated by burning the air/fuel mixture in the combustion process. When the third stream of gaseous materials is continuously subjected to analysis by a mass spectrometer, two signals are developed. A first output signal is generated on a continuous basis which is indicative of the ratio of oxygen to nitrogen in the third stream of gaseous material. This output signal is used to generate the control signal for application to the controlled source of oxygen. Another output signal is also generated which is indicative of the ratio of argon to nitrogen in the third stream of gaseous material. From this other output signal and the known, fixed mass injection rate of argon, a signal is generated whose strength is proportional to the air mass flow through the combustion process.

If one desires to obtain on a continuous basis an instantaneous indication of not only (a) the air to fuel ratio, and (b) the air mass flow, but also (c) the fuel mass flow of an air/fuel mixture being fed to a combustion process, the method described above is modified by continuously generating from the first output signal indicative of the oxygen to nitrogen ratio and the signal whose strength is proportional to the air mass flow through the combustion process a signal whose strength is proportional

to the fuel mass flow through the combustion process. This signal can be generated from the first output signal and the signal whose strength is proportional to the air mass flow because the fuel mass flow is mathematically related 5 to these quantities.

In still another form, the method of our invention may be used to obtain on a continuous basis for a moving internal combustion driven vehicle an instantaneous indication of (a) the air to fuel ratio, (b) the air mass flow, 10 (c) fuel mass flow, and (d) instantaneous fuel economy of an air/fuel mixture being fed to the combustion process. The method is similar to that heretofore described for obtaining (a), (b) and (c), but has some steps added thereto. Signals are continuously generated which are 15 indicative of vehicle speed and the density of the fuel being burned. One then, because of the mathematical interrelationship of the various quantities, can generate from the output signal indicative of the ratio of argon to nitrogen in the third stream of gaseous materials and the 20 signals indicative of vehicle speed and fuel density a signal whose strength is proportional to the instantaneous fuel economy of the driven vehicle.

The method taught in this disclosure may also be used to obtain on a continuous basis the oxygen concentration 25 in the exhaust gases. In this method, a signal is generated which is indicative of an oxygen to nitrogen ratio of a standard. Because of the mathematical interrelationship, a signal can be generated from the output signal indicative of the ratio of oxygen to nitrogen in the 30 third stream of gaseous material and the signal indicative of an oxygen to nitrogen ratio of a standard. The signal so generated will have a strength proportional to the oxygen concentration in the first stream of gaseous materials.

A preferred method of performing the invention will now be described, by way of example only, with reference to the drawings, in which:-

5 Figure 1 is a schematic drawing of different applications of the method of this invention to the monitoring of the exhaust gases generated by an internal combustion engine; and

10 Figure 2 is a schematic representation of the manner in which information may be processed in accordance with the teachings of the methods of this invention to obtain the data from the monitored combustion system.

15 The preferred embodiment of the method of this invention for obtaining the air to fuel ratio of an air/fuel mixture being fed to a combustion process will be illustrated. The other methods taught and claimed in this specification are derivatives of this basic method and they, in turn, will be illustrated in subsequent portions of this specification.

Air/Fuel Ratio.

20 A preferred embodiment of the method of this invention is illustrated in connection with the burning of gasoline in an internal combustion engine illustrated generally in the drawings by the numeral 10. This engine

is equipped with a carburetor 12 which is connected by means of a fuel supply line 14 to gasoline tank 16. In a known manner, fuel is drawn through the fuel supply line 14 to the carburetor 12 at which time it is mixed with air to form an air/fuel mixture. The air/fuel mixture, in turn, is burned in the cylinders of the internal combustion engine 10 to yield both the power which is used to drive the vehicle and the exhaust gases which are returned to the atmosphere. The exhaust gases pass out through an exhaust manifold 18 to an exhaust pipe 20 which may have a catalytic converter 22 associated therewith.

In the preferred embodiment illustrated herein, our method is used to obtain on a continuous basis an instantaneous indication of the air to fuel ratio of the air/fuel mixture being fed to the cylinders of the internal combustion engine 10. The method is initiated by continuously passing an air/fuel mixture through the combustion process occurring within the cylinders of the internal combustion engine to generate a first stream of gaseous material which is exhausted through the exhaust manifold 18 and the exhaust pipe 20. This first stream of gaseous material may contain (a) unburned fuel, (b) partially oxidized fuel, (c) carbon monoxide, (d) carbon dioxide, (e) water vapor, (f) nitrogen, (g) oxygen, (h) inert gases normally found in air, or (i) a mixture of any or all of (a) through (h).

In accordance with the teachings of our method as applied in a preferred embodiment, a sample portion of the first stream of gaseous material is withdrawn into a volume at a first pressure below atmospheric pressure. This sample portion is withdrawn by means of a sampling pipe 24, a capillary 26 and a first vacuum pump 28. The capillary 26 may have a diameter of approximately 0.3mm (orifice) and

be connected directly to the exhaust pipe 20 at a position before the catalytic converter 22. The first vacuum pump is a rotary oil type pump. The pressure between the capillary 26 and the first vacuum pump 28 is recorded by a
5 first vacuum gauge 30.

The first pressure below atmospheric pressure is a pressure that will not cause the water vapor contained in the sample portion to condense. Normally, this pressure in the preferred embodiment is less than 0.1 atmosphere. The
10 water vapor contained in the sample portion will not condense at this pressure and ambient temperatures. The sample portion continuously withdrawn forms a second stream of gaseous material confined within a tube 34. This second stream of gaseous material has the same compositional make-up
15 on a volume percentage basis as the first stream of gaseous material exhausted from the internal combustion engine 10 into the exhaust pipe 20. However, the two streams are at different pressures. The first stream would be at approximately one atmosphere and the second stream is
20 less than 0.1 atmosphere.

A source of oxygen gas 36 is connected by means of a tube 38 and an electrically controlled valve 40 to the tube 34 containing the second stream of gaseous material 32. Thus, in accordance with the teachings of a preferred
25 embodiment of the method of our invention, there is continuously provided a controlled source of oxygen addition to the second stream of gaseous material. The device controlling the addition of oxygen is the electrically controlled valve 40. This valve may be a valve such as a
30 Matheson Mass Flow Meter. A control signal can be applied to this valve to continuously control the amount of oxygen addition from the source of oxygen gas 36 to the second stream of gaseous material 32. In accordance with our

preferred embodiment, oxygen is added to the second stream of gaseous material at a rate proportional to the strength of the control signal applied to the electrically controlled valve 40.

5 In accordance with the teachings of our method, and as will be more fully explained hereafter, the control signal is developed to a strength on a continuous basis which results in the electrically controlled valve 40 being so set that the source of oxygen gas 36 adds to the second
10 stream of gaseous material sufficient oxygen that there is after oxygen addition a predetermined amount of oxygen in excess of that required. By this we means that we pre-select an excess amount of oxygen, for example, 5%, so that after the oxygen has stoichiometrically oxidized, any (a)
15 unburned fuel, (b) partially oxidized fuel and (c) carbon monoxide to (d) carbon dioxide and (e) water vapor there is a fixed amount of oxygen left over. In order to expedite matters, we provide a suitable oxidation catalyst 42 to ensure that the oxidizable components of the second stream
20 of gaseous material 32 are completely oxidized and that the predetermined excess amount of oxygen is in the gaseous components after passing through the catalyst.

A sample portion of the second stream of gaseous material 32 is continuously withdrawn into a tube 44. This
25 sample is withdrawn by means of a second vacuum pump 46 working through a capillary 48. The pump 46 and capillary 48 are similar to the pump 28 and the capillary 26 previously described. In accordance with the teachings of the preferred embodiment, the pressure of the tube 44 is
30 measured by a second pressure gauge 50 and in the preferred embodiment is 0.01 atmospheres. The sample portion continuously withdrawn forms a third stream of gaseous material 52. This third stream of gaseous material has the same compositional makeup based on fully oxidized carbon

and hydrogen on a molar basis as the second stream of gaseous material 32 plus the oxygen added but at a reduced pressure. The pressure of the second stream of gaseous material in the preferred embodiment was less than 0.1
5 atmosphere, while this third stream of gaseous material, in accordance with the preferred embodiment, is at a pressure of 0.01 atmosphere.

The third stream of gaseous material is continuously subjected to analysis by a mass spectrometer 54.
10 Mass spectrometers and their use are well known to a skilled artisan. A type of mass spectrometer that may be used is a UTI quadrupole. The use of the mass spectrometer will best be understood by referring to Figure 2.

In accordance with this preferred teaching, the
15 mass spectrometer 54 is used to generate on a continuous basis an output signal indicative of the oxygen and nitrogen signals in the third stream of gaseous material 52. The mass spectrometer generates this output signal by measuring the oxygen signal and the nitrogen signal in the
20 third stream of gaseous material.

The output signal developed by the mass spectrometer is fed to a microprocessor 56. The microprocessor generates a signal proportional to the oxygen signal, which is a control signal applied by means of electrical lead 58
25 to the electrically controlled valve 40. A feedback signal is applied from the electrically controlled valve 40 over electrical lead 60 to the microprocessor 56 so that the microprocessor can be assured that the valve has been set in accordance with the control signal applied to the valve.
30 From the valve control signal and the nitrogen to oxygen ratio, the microprocessor calculates the air to fuel ratio of the abovementioned first gas stream. The use of microprocessors, electrical leads and electrically controlled valves are state of the art activities for skilled artisans.
35 The only thing that may be special in our preferred

embodiment is that the oxygen concentration within the mass spectrometer is maintained nearly constant so as to increase signal response time. The microprocessor may also, by means of electrical lead 62, apply a signal to an output device 64 which could give a digital display of the air to fuel ratio being observed in the mass spectrometer so that a digital readout is available if one desired.

In accordance with the teachings of a preferred embodiment of this invention, the control signal for application to the electrically controlled valve 40 is continuously generated by the microprocessor 56 from the output signal generated by the mass spectrometer 54. This control signal strength is generated in a manner that it has two characteristics. A first characteristic of this control signal is that when the oxygen signal of the third stream of gaseous material is at a predetermined level, the control signal strength has a predetermined strength which ensures that a predetermined amount of oxygen in excess of that required to stoichiometrically oxidize the components mentioned above is added to the second stream of gaseous material 32. A second characteristic of the strength of the control signal is that when the oxygen signal of the third stream of gaseous material falls away from the predetermined level, the control signal has a strength that ensures an amount of oxygen greater than the predetermined amount of oxygen is added to the second stream of gaseous material. In this manner, the measured ratio of oxygen to nitrogen is returned to the predetermined level of oxygen and nitrogen. The instantaneous amount of oxygen being added to the second stream of gaseous material is a direct measure of the fuel to air ratio of the air/fuel mixture being burned in the combustion process. This direct measure may be displayed on the output device 64 through the action of the microprocessor 56.

Measuring Both Air/Fuel Ratio and
Hydrogen to Carbon Ratio

In accordance with another preferred embodiment of the method of this invention, one can measure both the air to fuel ratio and the hydrogen to carbon ratio of an air/fuel mixture being fed to a combustion process. In this case, the method steps are identical to those defined above for the method of obtaining the air to fuel ratio of an air/fuel mixture being fed to a combustion process. The 5 only differences between the methods will be the steps 10 described below.

When the third stream of gaseous material 52 is subjected to an analysis by the mass spectrometer 54 it not only generates on a continuous basis a first output signal 15 indicative of the ratio of oxygen to nitrogen in the third stream of gaseous material, but also another output signal. This other output signal is indicative of the ratio of oxygen to carbon dioxide in the third stream of gaseous material. The first output signal is used as previously 20 described for application to the microprocessor 56 in order to generate the control signal for application to the electrically controlled valve 40 in the manner described above.

The other output signal is used to continuously 25 generate a signal whose strength is proportional to the ratio of hydrogen to carbon in the fuel. This signal is generated in the microprocessor 56 from the data on the ratio of oxygen to carbon dioxide. A signal can be generated on this other signal because the oxygen required 30 is indicative of the amount of hydrogen and carbon in the fuel, and the amount of carbon dioxide is indicative of only amount of carbon in the fuel, therefore $\frac{O_2-CO_2}{CO_2}$ is proportional to $\frac{H}{C}$ in the fuel.

The signal whose strength is proportional to the ratio of hydrogen to carbon in the fuel in the air/fuel mixture being burned in the combustion process may also be fed to the output device 64 and there be digitally displayed in a manner well known to skilled artisans to indicate this information to the person desiring the same. Knowing the hydrogen to carbon ratio of the fuel being burned can be used to determine the exact amount of oxygen (or air) for stoichiometric oxidation of a fuel and is necessary to calculate the air to fuel ratio of a combustion process.

Measuring Both Air/Fuel Ratio and Oxygen Equivalents

The method of our invention may be used to measure both the air to fuel ratio and the oxygen equivalence of an air/fuel mixture being fed to a combustion process in the manner set forth below. By oxygen equivalence we mean the mass of air per unit time involved in the combustion process divided by the stoichiometric mass of air per unit time required.

Essentially, the same method is followed as was discussed in the preferred embodiment for measuring the air to fuel ratio. However, if one desires also to obtain the oxygen equivalence, the output signal from the mass spectrometer 54 is used for two purposes. A first purpose is to use the output signal to develop the control signal in the microprocessor 56 for application to the electrically controlled valve 40 in the manner aforescribed.

The same output signal indicative of the ratio of oxygen to nitrogen in the third stream of gaseous material can also be used for a second purpose. This second purpose is to generate on a continuous basis in the microprocessor 56 a signal whose strength is related to the oxygen equivalence for the air/fuel mixture being burned in the combustion process. The oxygen to nitrogen ratio is related

to oxygen equivalence because nitrogen is a measurement of air used in the combustion process and the oxygen is related to the amount of fuel used. It is desirable to know what the oxygen equivalence is so that that information may be used to determine the most efficient operational conditions of a combustion process.

Measuring Both Air/Fuel Ratio and Air Mass Flow

In accordance with still another embodiment of the method of this invention, a preferred embodiment is illustrated for measuring both the air to fuel ratio and the air mass flow of an air/fuel mixture being fed to a combustion process. Generally, this method is the same as the method described above for measuring only the air to fuel ratio. The changes that are necessary to obtain both measurements are as follows.

After the air/fuel mixture has been passed through the combustion process to generate the first stream of gaseous materials, argon is injected into that stream. In accordance with the teachings of this preferred embodiment, argon is continuously injected into the first stream of gaseous materials at a known, fixed mass injection rate. Reference is made to Figure 1 which shows a source of argon gas 66 connected by means of a valve 68 to the exhaust pipe 20 through which the first stream of gaseous materials is passing. The valve 68 is open so that a fixed, known mass injection rate of argon into the first stream of gaseous materials is established. For example, one may have an injection rate of 10 liter/min.

When the third stream of gaseous material 52 is subjected to analysis by the mass spectrometer 54, two signals are generated on a continuous basis. The first output signal is the signal indicative of the ratio of oxygen to nitrogen. This first output signal is used as aforescribed in order to generate the control signal for application to the controlled source of oxygen by means of the electrically controlled valve 40. The other output signal is indicative of the ratio of argon to nitrogen in the third stream of gaseous material. This other signal is applied to the microprocessor 56. The microprocessor, given the known, fixed mass injection rate of argon and the signal indicative of the ratio of argon to nitrogen in the third stream of gaseous material, is able to generate a new signal. This new signal has a strength which is proportional to the air mass flow through the combustion process. It is possible to calculate this air mass flow in the microprocessor because the change in argon concentration and the argon mass flow rate are known. It is of value to have data on air mass flow in order to engineer more efficient combustion devices.

Measuring Air/Fuel Ratio, Air Mass Flow and Fuel Mass Flow

Still another derivative of the method of our invention is one in which we can obtain not only the air to fuel ratio and the air mass flow, but also the fuel mass flow. This method is carried out just like the method described above for ascertaining the air to fuel ratio and air mass flow, but some minor changes are made thereto as follows.

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The development of a signal whose strength is proportional to the air mass flow through the combustion process as was described above. In order to determine the fuel mass flow through the combustion process, it is only 5 necessary in the microprocessor 56 to use the data contained in the first output signal indicative of the ratio of oxygen to nitrogen and the signal whose strength is proportional to the air mass flow through the combustion process to generate a signal whose strength is proportional 10 to the fuel mass flow through the combustion process. This newly generated signal may be applied to the output device 64 in order to obtain a display of the fuel mass flow.

The fuel mass flow may be generated from the data concerning air mass flow and the nitrogen to oxygen ratio 15 because the nitrogen to oxygen ratio is related to the air to fuel ratio which in combination with the air mass flow allows one to calculate the fuel mass flow. Knowing the fuel mass flow through the combustion process is important in order to determine the fuel economy.

20 Measuring Air/Fuel Ratio, Air Mass Flow, Fuel Mass Flow
and Instantaneous Fuel Economy

In accordance with a preferred embodiment, we can also use our method to derive an instantaneous indication for a moving, internal combustion driven vehicle of the air 25 to fuel ratio, air mass flow, fuel mass flow and instantaneous fuel economy of the air/fuel mixture being fed to the combustion process. This method is carried out in the same manner as described above for obtaining the first three pieces of information.

In order to generate the last piece of information, namely, instantaneous fuel economy, it is only necessary to modify our aforedescribed method by continuously generating signals indicative of vehicle speed and fuel density. A signal with respect to vehicle speed may be obtained from the speedometer cable, or, in the case of dynamometer testing, the road speed is available from the dynamometer. Normally, the signal for fuel density is a relatively constant number because most hydrocarbon fuels of gasoline nature have similar density.

Thereafter, it is possible to develop in the microprocessor, from the data contained in the other output signal indicative of the ratio of argon to nitrogen and the signals indicative of vehicle speed and fuel density, a new signal. This signal will have a strength which is proportional to the instantaneous fuel economy of the driven vehicle because the fuel mass flow multiplied by the density of the fuel divided by the instantaneous road speed is the instantaneous fuel economy. Such a number is a value in informing the driver whether or not he is operating the vehicle in an efficient and effective manner. The instantaneous value can be displayed on the output device 64 in order to inform the vehicle driver.

Measuring Air/Fuel Ratio and Oxygen Concentration

The preferred embodiment of the method for obtaining both the air to fuel ratio and the oxygen concentration in the exhaust gases of an air/fuel mixture being fed to the combustion process is similar to the first described method of obtaining the air to fuel ratio. The only difference is that there is provided a continuously generated signal indicative of an oxygen to nitrogen ratio of a standard. By this we mean there is developed a signal which can be related to the oxygen to nitrogen ratio of the standard and therefore the oxygen concentration in the exhaust gases can be determined.

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From this signal, indicative of an oxygen to nitrogen ratio of a standard, there can be generated, when the output signal of the actual oxygen to nitrogen ratio is used, a new signal whose strength is proportional to 5 the oxygen concentration in the first stream of gaseous material. This new signal may be developed in the micro-processor 56 because of the mathematical relationship between the two signals which provides the difference is due to oxygen in the sample stream. The new signal 10 generated may be displayed on the output device 64. The purpose of this signal is to display the measured oxygen concentration in the sample gas.

CLAIMS.

1. A method of continuously monitoring a combustion process comprising the steps of adding oxygen to a sample of the products of the combustion process under conditions sufficient to effect combustion of unburnt combustible material in the products of the combustion process; analysing the combustion products so obtained; generating a signal representative of the ratio of the oxygen and nitrogen contents of the combustion products so analysed;^{and} controlling in response to the signal the amount of oxygen added to the sample of the products of the combustion process so as to maintain a predetermined excess of oxygen in the analysed combustion products above that required for stoichiometric combustion of unburnt combustible material in the products of the combustion process.
2. A method according to claim 1 wherein the analysis is effected by mass spectrometry.
3. A method according to claim 1 or claim 2 wherein the sample of the products of the combustion process is obtained by withdrawing from a first stream containing the products of the combustion process a second stream containing the said products at a first pressure such that water vapour does not condense out of the second stream.
4. A method according to any one of claims 1 to 4^{wherein} the analysis is performed on a sample of the second stream obtained by withdrawing from the second stream a third stream containing the said products of combustion after any unburnt combustible material therein has reacted with the added oxygen, the third stream being at a second pressure such that, water vapour does not condense out of the second stream.
5. A method according to any one of claims 1 to 4 further comprising the step of deriving from the signal representative of the ratio of the oxygen and nitrogen contents a signal representative of the air-to-fuel ratio of the gases subjected to the combustion process.
6. A method according to any one of claims 1 to 5 further comprising the step of deriving from the signal representative of the ratio of the oxygen and nitrogen contents a signal representative of the oxygen equivalence of the mixture subjected to the combustion process.

7. A method according to any one of claims 1 to 6 further comprising the step of generating a signal representative of the ratio of the oxygen and carbon dioxide contents of the analysed combustion products and deriving therefrom an indication of the ratio 5 of the hydrogen and carbon contents of the gas mixture subjected to the combustion process.

2. A method according to any one of claims 1 to 7 further comprising the steps of adding an inert gas other than nitrogen to the products of the combustion process at a predetermined rate; and 10 generating a signal representative of the ratio of the inert gas and nitrogen contents of the analysed combustion products.. . . .

9. A method according to claim 8 further comprising the step of deriving from the signal representative of the ratio of the inert 15 gases and nitrogen contents a signal ^{representative} of the air mass flow through the combustion process.

10. A method according to claim 8 further comprising the step of deriving from the signals representative of the ratio of the oxygen and nitrogen contents and of the inert gas and nitrogen contents a signal representative of mass flow through the combustion process.

20 11. A method according to any one of claims 8 to 10 wherein the combustion process is carried out in an internal combustion engine of a vehicle, and further comprising the steps of generating signals representative of the speed of the vehicle, and of the density of the fuel supplied to the engine; and deriving from the 25 signals representative of the ratio of the inert gas and nitrogen contents, the speed of the vehicle and the density of the fuel, a signal representative of the fuel economy of the vehicle.

12. A method according to any one of claims 7 to 11 wherein the insert gas is argon.

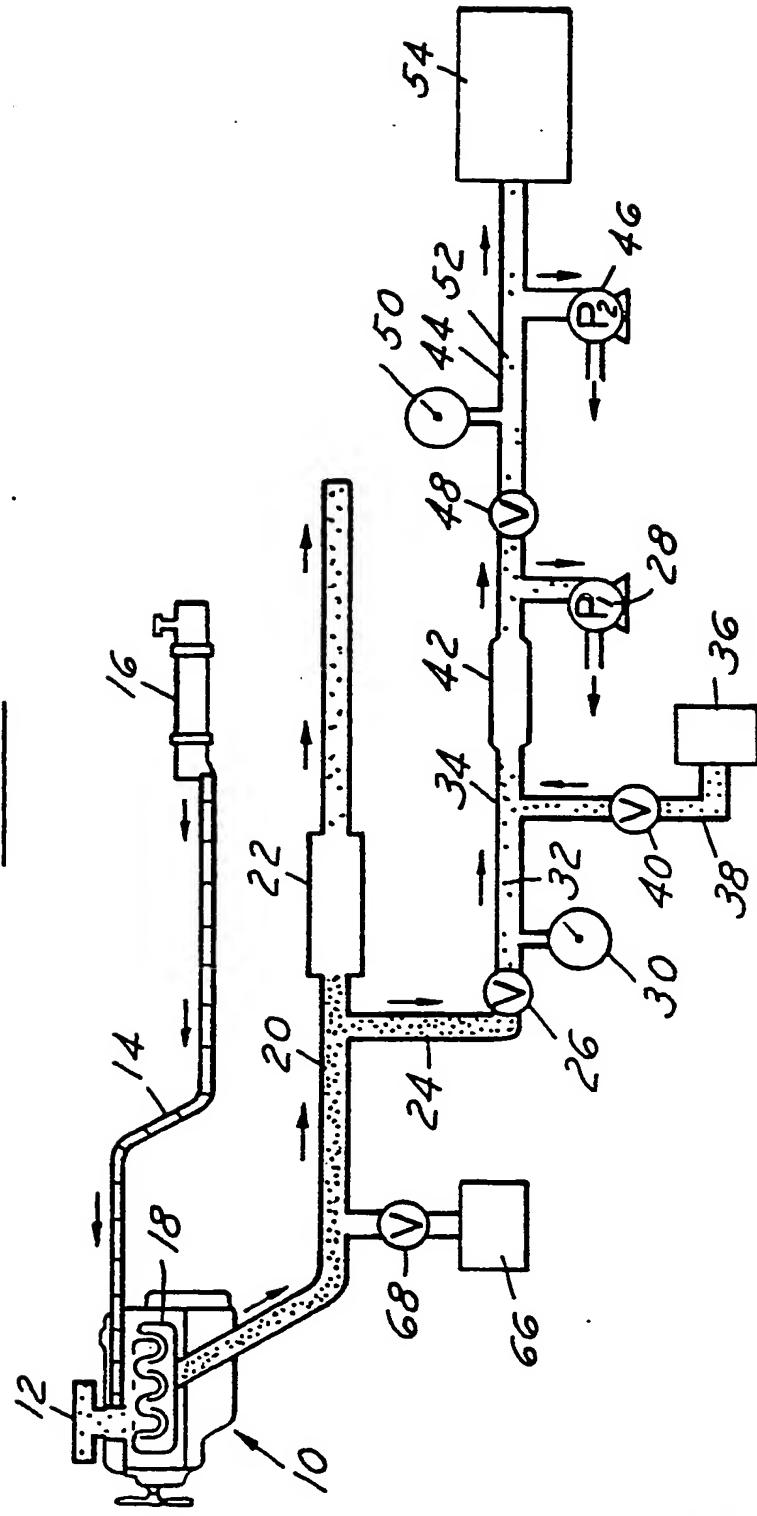
30 13. A method according to any one of claims 1 to 12 further comprising the steps of generating a signal representative of the ratios of oxygen to nitrogen in a standard; and deriving therefrom and from the signal representative of the ratio of the oxygen and nitrogen contents of the analysed combustion gases a signal representative of 35 the oxygen content of the products of the combustion process.

14. Apparatus for continuously monitoring a combustion process comprising means for withdrawing a sample of the products of the combustion process; means for adding oxygen thereto and for effecting combustion of unburnt combustible material in the products of the combustion process; means for analysing the combustion products so obtained; means for generating a signal representative of the ratio of the oxygen and nitrogen contents of the combustion products so analysed; and means operable in response to the signal for controlling ^{the} means for adding oxygen.
- 10 15. Apparatus according to claim 14 wherein the means for analysing the combustion products comprises a mass spectrometer.
16. Apparatus according to claim 14 or claims 15 wherein the means for controlling the means for adding oxygen comprises a microprocessor.
- 15 17. Apparatus according to any one of claims 14 to 16 further comprising means for adding an inert gas other than nitrogen to the products of the combustion process at a predetermined rate, and means for generating a signal representative of the ratio of the inert gas and nitrogen contents of the analysed combustion products.

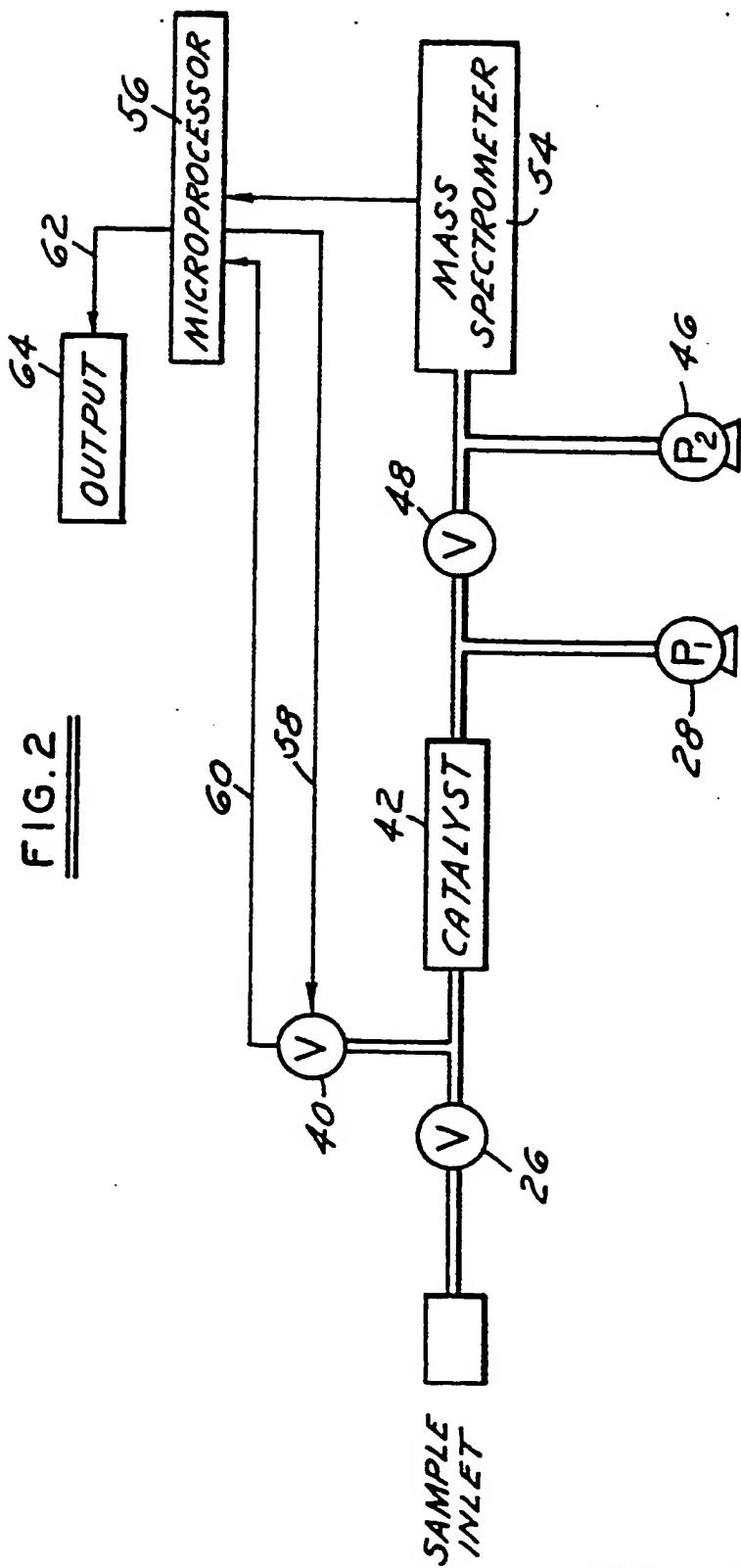
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FIG. 1

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